

Enhanced J/ψ production from double parton scatterings in nucleus-nucleus collisions at the Large Hadron Collider

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Abstract

A generic expression of double-parton scattering (DPS) cross sections in high-energy nucleus-nucleus collisions is derived as a function of the corresponding single-parton hard cross sections. We consider the case of prompt- J/ψ production and find that the DPS contributions represent (15–20)% of the total J/ψ cross section in lead-lead (Pb-Pb) collisions at the CERN Large Hadron Collider. In Pb-Pb at 5.5 TeV, about 300 double- J/ψ events are expected per unit midrapidity in the dilepton decay modes, per inverse-nanobarn. Double- J/ψ DPS production can partially explain the relatively less suppressed yields of J/ψ observed in Pb-Pb collisions at the LHC compared to results at lower collider energies.

Introduction – The production of heavy-quark bound states of the charmonium (J/ψ) and bottomonium (Υ) families in high-energy proton-proton (p-p) and nucleus-nucleus (A-A) collisions is governed by both perturbative and non-perturbative aspects of Quantum Chromodynamics (QCD) and has been extensively studied at fixed-target and collider energies [1]. A pair of charm or bottom quarks ($c\bar{c}$, $b\bar{b}$) is first produced mostly in a hard gluon-gluon collision with cross sections computable via perturbative QCD (pQCD) calculations. The subsequent evolution of the $Q\bar{Q}$ pair towards a color-singlet bound state is a non-perturbative process described in various theoretical approaches including color-singlet and color-octet mechanisms, non-relativistic QCD effective field theory, or color evaporation models (see e.g. [2] for a review).

In the case of A-A collisions, quarkonium has been since long proposed as a sensitive probe of the thermodynamical properties of the hot QCD medium produced in the course of the collision [3]. Analysis of quarkonia correlators and potentials in finite-temperature lattice QCD [4] indicate that the different $c\bar{c}$ and $b\bar{b}$ bound-states dissociate at temperatures T for which the color (Debye) screening radius of the medium falls below their corresponding $Q\bar{Q}$ binding radius. Experimental confirmation of such a quarkonia dissociation pattern would provide a direct means to determine the QCD transition temperature possibly reached in the system [5]. Somehow surprisingly, J/ψ production in lead-lead (Pb-Pb) collisions at the LHC [6–9] is observed to be less suppressed – compared to baseline p-p collisions at the same energy – than at the Relativistic Heavy-Ion Collider (RHIC) [10] despite the fact that the average medium temperature at LHC nucleon-nucleon center-of-mass (c.m.) energies ($\sqrt{s_{NN}} = 2.76$ TeV) is at least 30% higher than at RHIC ($\sqrt{s_{NN}} = 200$ GeV) [11]. At the LHC, the J/ψ suppression factor at low transverse momenta p_T amounts to $R_{AA} \approx 0.5$ whereas it was measured to be as low as $R_{AA} \approx 0.2$ – 0.3 at RHIC. Approaches combining J/ψ dissociation in a deconfined phase plus regeneration due to charm-quark recombination [12] can reproduce the observed trends in the data although the model parameters ($\sigma_{c\bar{c}}$ cross section, medium density, ...) need to be validated with other LHC observations.

In this paper we discuss and quantify the role of double-parton-scattering (DPS) processes as an extra source of J/ψ production in Pb-Pb collisions at LHC energies. Due to the fast increase of the parton flux at small parton fractional momenta, $x \equiv p_{\text{parton}}/p_{\text{hadron}}$ [13], the probability of having multiple hard parton interactions (MPI) occurring simultaneously at different impact parameters increases rapidly with collision energy and constitutes a significant source of particle production in p-p [14] and, in particular, nucleus-nucleus [15] collisions at semihard scales of a few GeV. The evidence for double parton scattering (DPS) processes producing two independently-identified hard particles in the same collision is currently based on p-p and p- \bar{p} measurements with final-states containing (i) multi-jets at $\sqrt{s} = 63$ GeV [16], 630 GeV [17], and 1.8 TeV [18], (ii) γ +3-jets at $\sqrt{s} = 1.8$ TeV [19] and 1.96 TeV [20];

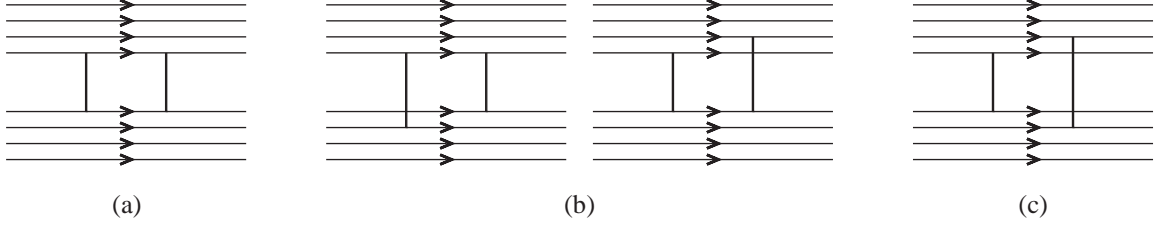


Figure 1: Schematic DPS contributions in A-A collisions: (a) The two colliding partons belong to the same pair of nucleons, (b) partons from one nucleon in one nucleus collide with partons from two different nucleons in the other nucleus, and (c) the two colliding partons belong to two different nucleons from both nuclei.

and (iii) W+2-jets at $\sqrt{s} = 7$ TeV [21]. Such measurements show an excess of events in various differential distributions with respect to the expectations from contributions from single-parton scatterings (SPS) alone. LHC p-p measurements of double- J/ψ production [22] as well as of single- J/ψ production as a function of the event multiplicity [23] have been also interpreted in the context of DPS [24–27] and MPI models respectively. The O(10%) “Cronin” enhancement observed in inclusive hadron production above $p_T \approx 2$ GeV/c in p-Pb at the LHC [28] can be also naturally explained as due to extra DPS contributions (although, the fragmentation of the partons into final-state leading hadrons, carrying out a fraction of the original momentum, washes out the effect).

We investigate DPS in A-A collisions following a previous similar study for proton-nucleus collisions [29]. The larger transverse parton density in nuclei compared to protons results in enhanced A-A DPS contributions coming from interactions where the two partons belong or not to the same pair of nucleons of the colliding nuclei (Fig. 1). Consequently, in Pb-Pb at LHC energies we expect a non-negligible probability of two parton-parton interactions independently producing two J/ψ mesons in the same nuclear collision.

Cross sections for double parton scattering in proton-proton and nuclear collisions – The DPS cross section in p-p collisions can be obtained from the convolution of parton distribution functions (PDF) and elementary cross section summed over all involved partons (see e.g. [30])

$$\begin{aligned} \sigma_{(pp \rightarrow ab)}^{\text{DPS}} = & \left(\frac{m}{2}\right) \sum_{i,j,k,l} \int \Gamma_p^{ij}(x_1, x_2; \mathbf{b}_1, \mathbf{b}_2; Q_1^2, Q_2^2) \\ & \times \hat{\sigma}_a^{ik}(x_1, x'_1, Q_1^2) \hat{\sigma}_b^{jl}(x_2, x'_2, Q_2^2) \\ & \times \Gamma_p^{kl}(x'_1, x'_2; \mathbf{b}_1 - \mathbf{b}, \mathbf{b}_2 - \mathbf{b}; Q_1^2, Q_2^2) dx_1 dx_2 dx'_1 dx'_2 d^2 b_1 d^2 b_2 d^2 b, \end{aligned} \quad (1)$$

where $\Gamma_p^{ij}(x_1, x_2; \mathbf{b}_1, \mathbf{b}_2; Q_1^2, Q_2^2)$ are double-PDF which depend on the longitudinal parton momentum fractions x_1 and x_2 , and on the transverse position \mathbf{b}_1 and \mathbf{b}_2 of the two partons undergoing the hard processes at the scales Q_1 and Q_2 , $\hat{\sigma}_a^{ik}$ and $\hat{\sigma}_b^{jl}$ are the parton-level subprocess cross sections, and \mathbf{b} is the impact parameter vector connecting the centers of the colliding protons in the transverse plane. The combinatorial factor $m/2$ accounts for indistinguishable ($m = 1$) and distinguishable ($m = 2$) final-states. Decomposing the double PDF into longitudinal and transverse components, with the transverse components expressed in terms of the overlap function $t(\mathbf{b}) = \int f(\mathbf{b}_1) f(\mathbf{b}_1 - \mathbf{b}) d^2 b_1$ for a given parton transverse thickness function $f(\mathbf{b})$, and making the assumption that the longitudinal components reduce to the “diagonal” product of two independent single-PDF, the cross section of double parton scattering can be finally expressed in the simple generic form [14]

$$\sigma_{(pp \rightarrow ab)}^{\text{DPS}} = \left(\frac{m}{2}\right) \frac{\sigma_{(pp \rightarrow a)}^{\text{SPS}} \cdot \sigma_{(pp \rightarrow b)}^{\text{SPS}}}{\sigma_{\text{eff,pp}}}, \quad (2)$$

where σ^{SPS} is the inclusive single-hard scattering cross section, computable perturbatively to a given order in α_s ,

$$\begin{aligned}\sigma_{(pp \rightarrow a)}^{\text{SPS}} &= \sum_{i,k} \int D_p^i(x_1; Q_1^2) f(\mathbf{b}_1) \hat{\sigma}_a^{ik}(x_1, x'_1) \times D_p^k(x'_1; Q_1^2) f(\mathbf{b}_1 - \mathbf{b}) dx_1 dx'_1 d^2 b_1 d^2 b \\ &= \sum_{i,k} \int D_p^i(x_1; Q_1^2) \hat{\sigma}_a^{ik}(x_1, x'_1) D_p^k(x'_1; Q_1^2) dx_1 dx'_1,\end{aligned}\quad (3)$$

and $\sigma_{\text{eff,pp}}$ is a normalization cross section representing the effective transverse overlap area of partonic interactions that produce the DPS process

$$\sigma_{\text{eff,pp}} = \left[\int d^2 b t^2(\mathbf{b}) \right]^{-1} \approx (13 \pm 2) \text{ mb}, \quad (4)$$

whose numerical value has been obtained empirically from fits to p-p and p- \bar{p} data [16–21].

To compute the DPS cross section in nucleus-nucleus collisions we proceed as done for proton-nucleus collisions in [29]. The parton flux is enhanced by the number A of nucleons in each nucleus and – modulo (anti)shadowing effects in the nuclear PDF (see below) – the single-parton cross section is simply expected to be that of p-p collisions, or more exactly that of nucleon-nucleon collisions (N-N), scaled by the factor A^2 , i.e.

$$\sigma_{(AA \rightarrow ab)}^{\text{SPS}} = \sigma_{(NN \rightarrow ab)}^{\text{SPS}} \int T_A(\mathbf{b}_1) T_A(\mathbf{b}_1 - \mathbf{b}) d^2 b_1 d^2 b = \sigma_{(NN \rightarrow ab)}^{\text{SPS}} \int T_{AA}(\mathbf{b}) d^2 b = A^2 \cdot \sigma_{(NN \rightarrow ab)}^{\text{SPS}}. \quad (5)$$

Here $T_A(\mathbf{b})$ is the nuclear thickness function as a function of the impact parameter vector \mathbf{b} connecting the centers of the colliding nucleus in the transverse plane, and $T_{AA}(\mathbf{b})$ the standard nuclear overlap function normalised to A^2 [31]. The DPS A-A cross section is thus the sum of three terms, corresponding to the diagrams of Fig. (1):

1. The first term corresponding to Fig. 1(a), similarly to the SPS cross sections Eq. (5), is just the DPS cross section in N-N collisions scaled by A^2

$$\sigma_{(AA \rightarrow ab)}^{\text{DPS,1}} = A^2 \cdot \sigma_{(NN \rightarrow ab)}^{\text{DPS}}. \quad (6)$$

2. The second term, Fig. 1(b), accounts for interactions with partons from one nucleon in one nucleus with partons from two different nucleons in the other nucleus¹,

$$\sigma_{(AA \rightarrow ab)}^{\text{DPS,2}} = 2 \sigma_{(NN \rightarrow ab)}^{\text{DPS}} \cdot \sigma_{\text{eff,pp}} \cdot T_{2,AA}, \quad (7)$$

with

$$T_{2,AA} = \frac{A-1}{A} \int T_A(\mathbf{b}_1) T_A(\mathbf{b}_1 - \mathbf{b}) T_A(\mathbf{b}_1 - \mathbf{b}) d^2 b_1 d^2 b = (A-1) \int d^2 r T_A^2(\mathbf{r}) = (A-1) \cdot T_{AA}(0). \quad (8)$$

3. The third contribution from interactions of partons from two different nucleon in one nucleus with partons from two different nucleons in the other nucleus, Fig. 1(c), reads

$$\sigma_{(AA \rightarrow ab)}^{\text{DPS,3}} = \sigma_{(NN \rightarrow ab)}^{\text{DPS}} \cdot \sigma_{\text{eff,pp}} \cdot T_{3,AA}, \quad (9)$$

with

$$T_{3,AA} = \left(\frac{A-1}{A} \right)^2 \int T_A(\mathbf{b}_1) T_A(\mathbf{b}_2) T_A(\mathbf{b}_1 - \mathbf{b}) T_A(\mathbf{b}_2 - \mathbf{b}) d^2 b_1 d^2 b_2 d^2 b = \left(\frac{A-1}{A} \right)^2 \int d^2 r T_{AA}^2(\mathbf{r}). \quad (10)$$

where the integral of the nuclear overlap function squared does not depend much on the precise shape of the transverse parton density in the nucleus and it amounts to $A^2/1.94 \cdot T_{AA}(0)$ for the hard-sphere approximation and $A^2/2 \cdot T_{AA}(0)$ for a Gaussian profile.

¹Possible extra “non-diagonal” interference terms, computed for light nuclei in [32], would lead to an increase of the value of $\sigma_{AA \rightarrow ab}^{\text{DPS,2}}$ but are effectively covered by the quoted uncertainty for $\sigma_{\text{eff,pp}}$, Eq. (4).

The factors $(A - 1)/A$ and $[(A - 1)/A]^2$ in the two last terms take into account the difference between the number of nucleon pairs and the number of *different* nucleon pairs. Adding (6), (7) and (9), the inclusive cross section of a DPS process with two hard parton subprocesses a and b in A-A collisions (with A large, so that $A - 1 \approx A$) can be written as

$$\begin{aligned}\sigma_{(AA \rightarrow ab)}^{\text{DPS}} &= A^2 \sigma_{(NN \rightarrow ab)}^{\text{DPS}} \cdot \left[1 + \frac{2(A-1)}{A^2} \sigma_{\text{eff,pp}} \int d^2r T_A^2(\mathbf{r}) + \left(\frac{A-1}{A^2} \right)^2 \sigma_{\text{eff,pp}} \int d^2r T_{AA}^2(\mathbf{r}) \right] \\ &\approx A^2 \sigma_{(NN \rightarrow ab)}^{\text{DPS}} \cdot \left[1 + \frac{2}{A} \sigma_{\text{eff,pp}} T_{AA}(0) + \frac{1}{2} \sigma_{\text{eff,pp}} T_{AA}(0) \right].\end{aligned}\quad (11)$$

In the simplest hard-sphere approximation for a nucleus with uniform nucleon density of radius $R_A = r_0 A^{1/3}$ and $r_0 = 1.25$ fm, the nuclear overlap function at $b = 0$ amounts to $T_{AA}(0) = 9A^2/(8\pi R_A^2) = 31.5 \text{ mb}^{-1}$ for ^{208}Pb - ^{208}Pb collisions. A direct evaluation of the integral using the measured Fermi-Dirac spatial density for the lead nucleus ($R_A = 6.624$ fm and surface thickness $a = 0.546$ fm) [33] yields $T_{AA}(0) = 30.4 \text{ mb}^{-1}$. Using the latter $T_{AA}(0)$ value and $\sigma_{\text{eff,pp}} = 13 \text{ mb}$, we compute the expression in parentheses in Eq. (11) – which quantifies the total DPS enhancement factor in A-A compared to N-N collisions, Eq. (6) – to be of the order of 200, dominated by the hard double nucleon scattering contributions, Fig. 1(c). The final DPS cross section “pocket formula” in nucleus-nucleus collisions as a function of the elementary nucleon-nucleon single-parton cross sections, can be obtained combining Eqs. (2) and (11):

$$\sigma_{(AA \rightarrow ab)}^{\text{DPS}} = \left(\frac{m}{2} \right) \frac{\sigma_{(NN \rightarrow a)}^{\text{SPS}} \cdot \sigma_{(NN \rightarrow b)}^{\text{SPS}}}{\sigma_{\text{eff,AA}}}, \quad (12)$$

with the effective A-A normalization cross section for Pb-Pb amounting to

$$\sigma_{\text{eff,AA}} = \frac{\sigma_{\text{eff,pp}}}{A^2 \left[1 + \frac{2}{A} \sigma_{\text{eff,pp}} T_{AA}(0) + \frac{1}{2} \sigma_{\text{eff,pp}} T_{AA}(0) \right]} = (1.5 \pm 0.2) \text{ nb}. \quad (13)$$

Numerically we see that whereas the single-parton cross sections in Pb-Pb collisions, Eq (5), are enhanced by a factor of $A^2 \approx 4 \cdot 10^4$ compared to that in p-p collisions, the corresponding double-parton cross sections are enhanced by a much higher factor of $\sigma_{\text{eff,pp}} / \sigma_{\text{eff,AA}} \approx 9 \cdot 10^6$.

Results – From Eqs. (12), with $m = 1$, and (13) we can compute the expected double-parton cross sections for J/ψ -pair production in Pb-Pb collisions using the single-parton J/ψ cross sections in nucleon-nucleon collisions, $\sigma_{(NN \rightarrow J/\psi X)}^{\text{SPS}}$. To obtain the latter quantity at all relevant collision energies, we use the color evaporation model (CEM) predictions of [34], properly scaled to match the existing p-p and p- \bar{p} data, and taking into account the shadowing of the nuclear PDF with respect to the free nucleons PDF [35]. The SPS cross sections for prompt J/ψ have been measured down to zero p_T in p- \bar{p} at $\sqrt{s} = 1.96$ TeV at rapidities $|y| < 0.6$ [36] and in p-p at $\sqrt{s} = 2.76$ TeV ($|y| < 0.9$ [37], $2 < |y| < 4.5$ [38]) and 7 TeV ($|y| < 0.9$ [39], $1.6 < |y| < 2.4$ [40], $2 < |y| < 4.5$ [41]) after subtraction of the decay contributions from bottom mesons². The extrapolations to total J/ψ cross sections at the LHC have been obtained by integrating a Gaussian distribution fitted to the data points measured at different y . The Tevatron midrapidity cross section has been extrapolated to full- y based on the prescription proposed in [43]. The obtained values, with their propagated uncertainties, are listed in Table 1 and shown as data points in Fig. 2 (top).

The corresponding CEM predictions for $\sigma_{(pp \rightarrow J/\psi X)}^{\text{SPS}}$ [34], scaled by a K-factor of two³ to match the experimental results, are also plotted as a solid curve. The values for $\sigma_{(NN \rightarrow J/\psi X)}^{\text{SPS}}$ are obtained from the CEM predictions scaled to the p-p data and normalized to the ratio of the p-p over N-N cross-sections, where the latter have been determined using the EPS09 nuclear PDF [45]. In the $x \approx 10^{-3}$, $Q^2 \approx m_{J/\psi}^2$ region relevant for J/ψ production at the LHC, the Pb gluon PDF is moderately depleted, by a factor of $(1 - S_{g,\text{Pb}}) \approx 15\%$ – 25% with respect to the free nucleon density, resulting in a reduction of the $g g \rightarrow J/\psi + X$ yields compared to the p-p data by a factor of $(1 - S_{g,\text{Pb}}^2) \approx 30\%$ – 40% (dashed-dotted line in Fig. 2, top). The EPS09 uncertainties, of the order of $\pm 10\%$ – 15% , have been propagated in quadrature with those associated with the data extrapolation, into the N-N cross sections quoted in Table 1.

²Decay contributions from higher-mass χ_c and ψ' resonances increase the prompt- J/ψ yields by about 35% [42].

³More recent CEM calculations [44], with higher values of the c-quark mass and lower renormalization scales μ_R , reproduce well the LHC data. Note also that feed-down χ_c, ψ' contributions are not included.

Table 1: Total cross sections at LHC energies for the production of prompt J/ψ in single-parton-scatterings (SPS) in p-p, N-N, Pb-Pb collisions, and of prompt J/ψ -pairs in double-parton-scatterings (DPS) in Pb-Pb. The p-p values are extrapolated from experimental data, the N-N values are based on the CEM (normalized to p-p,p- \bar{p} data) including EPS09 nuclear PDFs, and the Pb-Pb results are derived from the N-N cross sections via the quoted equations.

Process	Cross section	$\sqrt{s_{NN}}$ (TeV)			
		1.96	2.76	5.5	7.0
σ^{SPS} (p-p, p- \bar{p} $\rightarrow J/\psi X$) [μb]	measured (extrapolated)	$25. \pm 9.$	$28. \pm 8.$	—	$49. \pm 9.$
σ^{SPS} (N-N $\rightarrow J/\psi X$) [μb]	CEM+EPS09 PDF, Eq. (3)	$15. \pm 5.$	$19. \pm 6.$	$26. \pm 8.$	$29. \pm 9.$
σ^{SPS} (Pb-Pb $\rightarrow J/\psi X$) [mb]	Eq. (5)	650 ± 200	850 ± 250	1100 ± 350	1250 ± 350
σ^{DPS} (Pb-Pb $\rightarrow J/\psi J/\psi X$) [mb]	Eqs. (12)–(13)	75 ± 28	120 ± 45	225 ± 80	280 ± 100

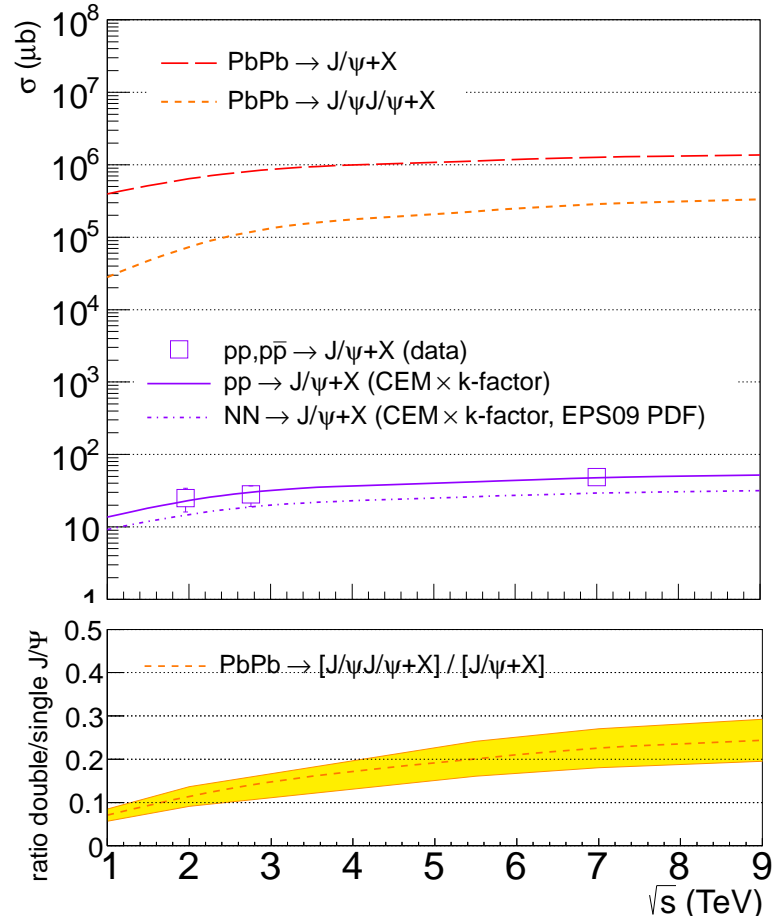


Figure 2: Top: Prompt- J/ψ production cross sections in single-parton interactions in p-p, N-N, and Pb-Pb collisions, and for double-parton $J/\psi J/\psi$ in Pb-Pb, as a function of c.m. energy. Bottom: Fraction of prompt- J/ψ events where a pair of J/ψ is produced in Pb-Pb collisions, as a function of c.m. energy (the band indicates the size of the associated uncertainty).

The uppermost curves in the top panel of Fig. 2 show the resulting Pb-Pb cross sections for single- and double- J/ψ production, whereas their ratio is shown in the bottom panel. Single prompt- J/ψ cross sections amount to about 1 b at the LHC (dashed curve), and 10% to 30% of such Pb-Pb collisions are actually accompanied⁴ by the production of a second J/ψ from a double-parton-scattering interaction (dotted curve). It is interesting to note that the rise of the DPS/SPS ratio appears to slow down at the highest $\sqrt{s_{\text{NN}}}$ as the shadowing of the nuclear gluon PDFs (which enters squared in the numerator but only linearly in the denominator) increases⁵, thereby reducing the total double- J/ψ yields. The uncertainty of the DPS fraction (shown as a yellow band in Fig. 2, bottom) amounts to about $\pm 20\%$ including, in quadrature, the uncertainties from the EPS09 PDFs and from the effective $\sigma_{\text{eff,AA}}$ value, Eq. (13). The dominant uncertainties in the absolute J/ψ cross sections, coming from the experimental data extrapolation, cancel out in the single-to-double J/ψ ratio.

The computed Pb-Pb cross sections are baseline theoretical results – for “minimum bias” (MB) collisions without any selection in the reaction centrality – including nuclear PDF modifications but no final-state effects (e.g. from color deconfinement and/or charm recombination) which can modify the final measured yields. Experimentally, Pb-Pb collisions at 2.76 TeV show a reduction factor of ~ 2 of the MB J/ψ yields with respect to p-p, i.e. $R_{\text{AA}}^{\text{MB}} = \sigma_{\text{AA}}/(A^2 \cdot \sigma_{\text{pp}}) \approx 0.5$, whereas the corresponding value at RHIC amounts to $R_{\text{AA}}^{\text{MB}} \approx 0.4$. At the LHC energy, according to Fig. 2 (bottom), we expect a $\sim 15\%$ increase of the prompt J/ψ yields due to DPS contributions (which are negligible at RHIC), and thus for the *same* medium-induced prompt- J/ψ suppression at both energies, the R_{AA} can be higher at the LHC due to the extra initial-state J/ψ production. The effect of the DPS contributions on the R_{AA} ratios is much more significant for *central* A-A collisions since the dominant component scales as the square of the nuclear overlap function, Eq. (10). The production of double- J/ψ is thus strongly biased towards the most central collisions with lowest impact parameter. This fact can also explain the much less depleted J/ψ yield in central Pb-Pb at 2.76 TeV ($R_{\text{AA}}^{\text{cent}} \approx 0.5$) than at RHIC ($R_{\text{AA}}^{\text{cent}} \approx 0.2\text{--}0.3$). A quantitative analysis of the centrality dependence of the DPS J/ψ yields is object of a coming study [47].

A confirmation of our predictions would be possible by measuring the cross sections for the concurrent production of two J/ψ mesons in the same Pb-Pb interaction via their visible dilepton decay channels. At LHC energies, the cross section per unit-rapidity for single- J/ψ amounts to $d\sigma_{J/\psi}/dy \approx \sigma_{J/\psi}/8$ at the (low- p_T) rapidities covered by ALICE (at $y = 0$) and CMS (at $y = 2$), the detector acceptance and reconstruction efficiencies reduce the measured yield by factors of $\sim 12\text{--}14$ [9, 40], and the dilepton branching ratio amounts to 0.0594. Squaring all these quantities for the case of double- J/ψ production results in a final reduction factor of order $3 \cdot 10^{-7}$ for both rapidity ranges. Thus, at 5.5 TeV one would expect a visible DPS cross section of about $d\sigma_{J/\psi, J/\psi}^{\text{DPS}}/dy|_{y=0(2)} \approx 75$ nb per dilepton decay mode, i.e. about 300 double- J/ψ events per unit-rapidity in the four combinations of dielectron and dimuon channels in 1 nb^{-1} of integrated luminosity, assuming no in-medium suppression. The same estimates for the 15 (150) μb^{-1} of Pb-Pb data already collected at 2.76 TeV result in about 2 (20) double- J/ψ events in ALICE (CMS) at mid (forward) rapidities. The very large combinatorial background of dilepton pairs with invariant masses around $m_{J/\psi}$ makes however this measurement very challenging on an event-by-event basis (except maybe at higher p_T values where the background is smaller).

Conclusions – We have derived the general expression for double-parton-scattering (DPS) cross sections in heavy-ion collisions as a function of (i) the elementary single-parton cross sections in nucleon-nucleon collisions, and (ii) an effective $\sigma_{\text{eff,AA}}$ parameter describing the transverse density of partons in the system. The DPS cross sections in Pb-Pb are found to be enhanced by a factor of 200 compared to the A^2 -scaling of single-parton scatterings. We have studied the case of double- J/ψ production at LHC energies and found that the DPS contributions represent (15–20)% of the total prompt- J/ψ cross section and could well explain the relatively less suppressed J/ψ yields measured at $\sqrt{s_{\text{NN}}} = 2.76$ TeV compared to results at lower collider energies. At 5.5 TeV, about 300 double- J/ψ events are expected per unit rapidity in the dilepton decay channels (in the absence of final-state suppression) for an integrated luminosity of 1 nb^{-1} , providing a quantitative test of the predictions presented here.

⁴DPS cross sections have to be understood as *exclusive* values which are part of the total inclusive single-parton cross section [46].

⁵We note that both MPI and gg fusion (leading to shadowing of nuclear PDF) are counterbalancing processes characteristic of the multi-scattering dynamics dominating at small- x .

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